Virtual Antenna Arrays
Results and ongoing studies

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Abstract— **This paper describes results regarding cooperative MIMO relaying(CMIMOR), a.k.a virtual antenna arrays(VAA), obtained by Miguel Rodriguez and ongoing work by Fredrik Strömberg. A comparison between CMIMOR, traditional cellular networks and multi-hop networks showed that CMIMOR could increase the link throughput by a factor of 2, in a typical scenario using a relay power allocation algorithm. As an extension, a study regarding the system throughput is ongoing and the research approach will be revised at the end of this paper.**

I. Introduction

The mobile telephony market has grown enormously in Sweden during the last years. The users are tending to use the services more and more, up to date basically voice and SMS [1] [2]. To meet this demand the basic strategy has so far been to enhance the modulation and the coding technique and to put up some new base stations. But today's systems has almost reached the Shannon capacity limit and the most expensive thing in the network is to put up a new base station. Instead new strategies have to be deployed to make the cost reasonable or even lower the cost.

One solution could be to consider multiple-input multiple-output (MIMO)systems. It has shown an significant increase in spectral efficiency compared to a single-input single-output(SISO) system [4]. A MIMO system consists of several transmit and receive antennas and it can be realized with multielement array antennas. The possibility to implement a multielement antenna array into a mobile terminal is rather limited due to general expectations and demands for smaller and lighter terminals. To solve this problem a new approach has been suggested and it is called cooperative MIMO relaying(CMIMOR) or Virtual Antenna Array(VAA). The goal is to emulate a MIMO system and implement it within a mobile telecommunication system thus take benefit of the extraordinary spectral efficiency of MIMO systems.

II. Concepts of virtual antenna arrays(VAA)

VAA emulates a MIMO channel and the optimum design rule is to have as many transmitting antennas as receiving antennas, thus a VAA system is created by forming a VAA group consisting of as many terminals as transmitting antennas. The VAA group consists of relays and the receiver terminal. The relays could be other mobile terminals or fixed relays. The relays are forwarding the data to the receiver and it can be done in a regenerative or non-regenerative fashion. (See Fig.1) The signaling from the base station(BS) is done as if a real MIMO channel would be present. For further details see [5].

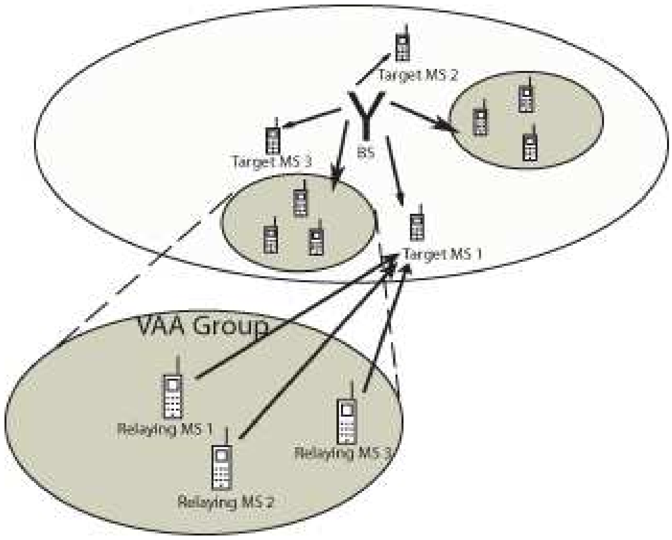

Fig. 1. Virtual Antenna Array System

III. Master thesis done by Miguel Rodrigues

The performance of a CMIMOR(VAA) link was studied in the down-link case in this thesis. For one isolated cell where the interference were modelled as random gaussian noise. The performance was measured in terms of maximal throughput and compared to links in traditional cellular system and multi-hop system. The relays are working in non-regenerative way which is preferable if you have time-restrained services and have good channel conditions [10]. The link throughput was simulated in Matlab. There were as many channels as transmitters so there was no intra-cell interference among the relays. Continuous transmission was considered.

The relays that will form the VAA group were chosen according to the highest signal-noise ratio(SNR) to the destination. 4 different heuristic schemes for allocating power to the relays were considered. Heuristic in the sense that the experienced SNR at the receiver is derived for a case where the relay stations(RS) uses all the aggregate total power, e.g we have an power constraint and this scheme is derived for a VAA link with one transmitter, one relay and one receiver [9] [11]. An interesting detail was to see how a scheme with weighted SNR ,proposed by Peter Larsson, would stand against the distance scheme that is used in some recently proposed articles, e.g. [5] [6] [7] [8] [12]

- Weighted SNR scheme, $P_k = \frac{CP_{RS}|a_k|^2}{\sum |a_k|^2}$
- Addition scheme, $P_k = CP_{RS}(\Gamma_{1,k} + \Gamma_{2,k})$
- Multiplication scheme, $P_k = CP_{RS}(\Gamma_{1,k}\Gamma_{2,k})$
- Distance scheme, $P_k = \frac{P_{RS}}{M}$

Where;

P_k - power assigned to each relay

$\Gamma_{1,k}$ - SNR for the first link, BS-RS

$\Gamma_{2,k}$ - SNR for the second link, if RS_k would use all aggregate relay station transmit power by itself.

$a_k = \sqrt{\frac{\Gamma_{1,k}\Gamma_{2,k}(\Gamma_{1,k}+1)}{(\Gamma_{1,k}+\Gamma_{2,k}+1)}}$

C - Constant to balance the total power constraint.

M - Number of relays.

For a fair comparison between the different systems the constraints must be the same such as: the same channel, the same total BW and the same total power.

- $P_{tot} = P_{BS} + P_{RS_{tot}}$
- $P_{RS_{tot}} = \frac{P_{BS}}{10}$
- $N_{Tx} = N_{Rx} = N_{RS} + 1$; gives the optimum capacity
- $W = \frac{W_{tot}}{N_{Tx}}$; Total bandwidth(BW) shared among all transmitter
- $C_{tot} = \sum_{i=0}^{N_{Tx}} Wlog_2(1 + \Gamma_i)$; total throughput on the link where Γ_i is the SNR on each link after single value decomposition(SVD).

A. Results and main conclusions

The VAA link with the weighted SNR relay power allocation scheme gives the highest average throughput in all scenarios but one. When there is a high number of relay stations compared to the total amount of mobiles then a VAA link with a distance scheme power allocation algorithm gives the highest average throughput.

When a direct link to the receiver exists then the throughput increases by about 20%.

IV. Ongoing work: System level aspect

Earlier work done on system level has been conducted on a WCDMA system [12]. One big disadvantage with that study was that the interference from the relays were neglected. Although the relay groups were formed by the spatially closest to the receiver, I believe that in a sparse environment that the interference might have a significant impact on the overall performance. Also choosing the spatially closest might not be the optimal because fading may higher received signal power from a relay further away.

In this ongoing work we will take those things into consideration.

The main object in this thesis is to evaluate the capacity in a VAA SDMA/TDMA system in terms of system throughput. The capacity/coverage will be compared with a traditional cellular system, omnidirectional antennas,(if time multiple antennas with beam forming will be included) and with multi-hop networks.

A power allocation algorithm, previously performing well on link level simulations done by Miguel Rodriguez, will be implemented. The throughput will also be compared to results obtained by Miguel Rodriguez on link level simulation, to determine if the interference has a great impact on the result. The downlink will be considered. If time allows different channel allocation strategies will be implemented.

A. Research approach

The system will be simulated using Matlab and the main structure is as follows:

1) The VAA group will be grouped by the highest effective SINR instead of the spatial closest.
2) The interference produced by the VAA will not be neclected.
3) The relayed power will be allocated accordingly to a scheme, Peters scheme, that has performed really well during link-level simulations and overall performed much better than the distance allocation scheme where all spatial closest relay stations are transmitting with equal power. The total received power from the relays should be the equal to the received power from the base station since it has shown to give the highest throughput. [9]
4) No STC is deployed since we want to draw some conclusions from the link-level study performed by Miguel where it is not used.
5) Non-regenerative relays are deployed, e.g amplify and forward, since we are interested in the high SINR domain where it has been pointed out earlier,for a (1,1,1) link, that it performs as well as regenerative relaying regarding the BER rate.
6) No blocking or dropping will be considered. The users will be served in a best effort mode. In some time this could mean an instantaneous SINR below some imaginary $SINR_{target}$ that could be interpreted as dropping or blocking.
7) The access scheme deployed is a TDMA slot frame with a spatial reuse. We could think of the equivalent MIMO channel as min$\{N_{tx}, N_{rx}\}$ independent sub channels transmitting at same time separated in the spatial dimension. Thus emulating an SDMA scheme (compare to beam forming).
8) The maximum throughput is achieved for equal amount of transmitters as receivers. This means that the VAA group will be consisted of $N_{tx} - 1$ relays.
9) Two allocation strategies deployed depending on load, fixed channel allocation and dynamic channel allocation. For heavily loaded systems FCA is performing as well as DCA and will then be used.

V. Conclusion

Earlier studies shows a great possibility to achieve a very high bandwidth efficiency and thereby a high link throughput for a VAA system. The system throughput is now going to be investigated and compared to other kinds of networks in an attempt to decide what is the most cost efficient system and thereby more promising for use in future networks.

REFERENCES

[1] Post och telestyrelsen, ”Svensk telemarknad 2002”, *http://www.pts.se/Archive/Documents/SE/Svensk%20telemarknad%202002%20-%20PTS-ER-2003-21.pdf*

[2] SIKA, ”SIKAs rapport om telemarknaden 2002”, *http://www.sika-institute.se/utgivning/ss2003_4.pdf*, Sep.2003

[3] C.E Shannon, ”The mathematical theory of information”, *University of Illinois press*, Urbana, Illinois, 1949

[4] G.J Foschini, M.J Gans, ”On limits of wireless communications in a fading environment”, *Wireless personal communications*, vol.6, No. 3, pp.311-335, Mar. 1998

[5] M. Dohler, ”Virtual Antenna Arrays”, WWRF2001, *electr. conference CD-ROM*, Paris, France, Dec. 2001

[6] M. Dohler, E. Lefranc, H. Aghvami, ”Virtual Antenna Arrays for future mobile communication systems”, *IEEE ICT 2002*, Beijing, China, Jun. 2002

[7] M. Dohler, J. Dominguez, H. Aghvami, ”Link capacity analysis for Virtual Antenna Arrays”, *VTC Fall*, Vancouver, Canada, Sept. 2002

[8] M. Dohler, H. Lefranc, H. Aghvami, ”Space-time block codes for virtual antenna arrays”, *PIMRC*, Lisbon, Portugal, Sept. 2002

[9] M. Rodriguez, ”Cooperative MIMO Relaying”, *M.Sc. Thesis*, RST KTH, Jan. 2004

[10] M.O. Hasna M.S. Alouini, ” Performance analysis of two-hop relayed transmissions over Rayleigh fading channels ”, *Vehicular Technology Conference*, Volume: 4 , 24-28 Sept. 2002

[11] P. Larsson, ”Large-scale relaying network with optimal coherent combining under aggregate relay power constraint”, *In Proc. FTC2003*, Beijing, China, pp.166-170 9-10 Dec. 2003

[12] M. Dohler, Z. Zeng, H. Aghvami, ”System performance of a W-CDMA based network with deployed virtual antenna arrays”, *ICT2002*, Beijing, China, Jun. 2002

[13] Z. Tabakovic, ”Performance analysis of channel assignment schemes”, *Vehicular Technology Conference, 2001*, vol.2, 6-9 May 2001, pp.911 - 915